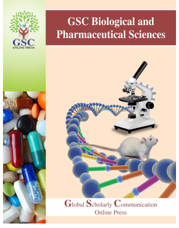
GSC Biological and Pharmaceutical Sciences, 2020, 11(02), 257–264

Available online at GSC Online Press Directory

GSC Biological and Pharmaceutical Sciences

e-ISSN: 2581-3250, CODEN (USA): GBPSC2

Journal homepage: https://www.gsconlinepress.com/journals/gscbps



(REVIEW ARTICLE)

A review on waste absorption efficiency of different extractive integrated multi-trophic aquaculture (IMTA) species: Implications in coastal and offshore aquaculture waste management

Jumah Yashier Upling [1, 2, *]

[1] *Aquaculture Department, College of Fisheries, Mindanao State University - Tawi-Tawi College of Technology and Oceanography, Sanga-Sanga, Bongao 7500, Tawi-Tawi, Philippines.*
[2] *Institute of Aquaculture, College of Fisheries and Ocean Sciences, University of the Philippines Visayas, Miagao 5023, Iloilo, Philippines.*

Publication history: Received on 16 May 2020; revised on 21 May 2020; accepted on 24 May 2020

Article DOI: https://doi.org/10.30574/gscbps.2020.11.2.0141

Abstract

The integrated multi-trophic aquaculture also known as the “IMTA” system is one of a sustainable and eco-friendly approach among aquaculture activities. This aquaculture practice does not compromise the well-being of the natural ecosystem because of the synergistic functions of different extractive species where both inorganic and organic waste have been regulated into an optimum level. The recycling of waste within the system is the most vital strategy to alleviate the impact on the neighboring natural habitats. However, the selection and good combination of the extractive species should be considered for an efficient and effective IMTA system. Thus, this review paper investigated several extractive species used in the IMTA system. Overall studies suggest that viable extractive species of mussel, sea cucumber, sea urchins, and macroalgae carried out different strategies in converting waste from aquaculture fed-species. However, among suspension extractive species, sea cucumber showed exemplary performance in the reduction of feces of the cultured fed-species. Thus, a combination of sea-cucumber, macroalgae and finfish is highly recommended in the IMTA system.

Keywords: Aquaculture; Integrated; Echinoderm; Eco-friendly; Bio-deposit feeder.

1. Introduction

Most marine finfish cages are operated as flow-through net-pen systems. This means that water is transported through the cages by currents, resulting in an incomplete utilization of feed resources and a direct release of reduced quality water, laden with both particulate and dissolved nutrients to the environment. Integrated multi-trophic aquaculture (IMTA) has been proposed for mitigating aquaculture waste release, which, as compared to other accompanying methods (i.e. improved maintenance, feed development, etc.), has advantages that may include a reduced “ecological footprint”, economic diversification and increased social acceptability of finfish culturing systems. The practice of IMTA combines, in the right proportions, the cultivation of fed aquaculture species (principally finfish) with inorganic extractive aquaculture species (principally seaweeds) and organic particulate extractive aquaculture species (principally suspension- and deposit-feeders) [1]. IMTA has been reported to outperform conventional polyculture with respect to environmental remediation, productivity in brackishwater area [2].

---

[*] Corresponding author: Jumah Yashier Upling; phone: +639778166822; email: ajofflink@gmail.com

In IMTA systems, fed fish can be placed at the upper and middle trophic levels while organic extractive species (mussels) at the middle and bottom level so that they can consume particulate organic nutrients (waste feed and feces). Seaweeds could be placed a little far away from fed and organic extractive species so that they can consume dissolved inorganic wastes, including ammonia, phosphorus, and nitrates [3].

IMTA contributes to a reduction in sedimentary loads of organic waste, and thereby to an improvement in sediment and water quality through the extractive process of co-cultured species situated beneath the fish cage. Absorption efficiency (AE) is an important variable to determine within the IMTA infrastructure in order to quantify the overall reduction in quality (organic content) of the suspended particulate waste material as it is converted and re-deposited by extractive species. With the information in AE, it will be possible to estimate the potential for reduction in organic loading by extractive species occurring at IMTA sites compared to that of traditional aquaculture operations. Some of the factors that can impact AE include: feeding physiology such as the selective feeding observed in deposit-feeding; the structure and function of the gut; the addition of mucous to the feces; and gut passage time [4].

Several regions have been adapting IMTA as a viable aquaculture option in brackishwater areas that warrant environmental sustainability [5]. The way to minimize the disturbance of aquaculture to protect the ecosystem was also reported in Bay, where IMTA is practiced and coined as highly ecological efficient [6].

2. Echinoderms as a suspension and deposit-feeder extractive IMTA species

Suspension-feeding sea cucumbers may have higher absorption efficiency than deposit-feeding species because they are processing a suspended food supply that may be higher in quality than the composition of benthic sediments [4]. Like in orange-footed sea cucumber *Cucumaria frondosa* which found absorbing approximately 70% of organic material when feeding in the natural environment, with the potential to increase when exposed to higher quality material [4]. While California sea cucumber *Parastichopus californicus* is known to reduce the total organic carbon and total nitrogen contents of the sable feces by an average of 60.3% and 62.3%, respectively [7]. It was even reported recently that sea cucumber *Actinopyga bannwarthi* expressed higher digestibility of the gilthead seabream farm-waste feed than the sea urchin (11.7-45.9% and 3.8 - 16.3% respectively) [8].

Sea cucumber is known to be a good candidate for a co-culturing extractive species and that it can consume and reduce the biodeposit loads from aquaculture systems. This was observed in *Apostichopus japonicus* (with an initial length of 2.7±0.7 cm and weight of 1.0±0.7) grew to 17.0 cm (±2.3 cm) and 147.4 g (±66.7 g) co-cultured with rockfish in IMTA, with a final survival of approximately 74%, displaying a very fast (3.5 times) growth rate compared with those obtained from a sowing culture on natural sediments [9]. Higher survival (96%) and significantly higher specific growth rate (1.9%) than those at the control site (1.2%) were obtained using the same species cultivated below fish cages in Gokasho Bay, central Japan [10]. Other species such as California sea cucumber *P. californicus* in suspended culture underneath net pens of sablefish at an experimental IMTA site, grew significantly faster than individuals grown ~250m away from the farm with a high survival rate (99.5%) [7]. The same species showed a mean weight increased of 42.9 g in approximately 12 months (average growth rates at both sites ranged from 0.061 to 0.158 g d^{-1}) co-cultured with suspended Pacific oyster *Crassostrea gigas* [11].

Other potential species belong to Echinoderms that manifested to consume and subsequently reduced the organic content is the green sea urchin *Strongylocentrotus droebachiensis*. It was observed that *S. droebachiensis* consumed sablefish waste at a dry weight ingestion rate of 0.43±0.039 g $individual^{-1}$ d^{-1} and absorbed 40±4.84% of the organic material ingested [12]. Another species of sea urchin *Paracentrotus lividus*, a macroalgivore, was evaluated in a semi-commercial land-based IMTA system. This *P. lividus* fed IMTA- produced *Ulva lactuca* which exhibited a high somatic growth rate (1.4mm $month^{-1}$), high gonad somatic index (SGI), and high quality, bright-orange gonads. Their assimilated nitrogen (N) was 13.86%, however, their feces contained 19.9% of it. And it was also mentioned that 4.96 kg of N was released during spawning, which occurred in January, May, and December [13]. Their feeding preference could be utilized to control biofoulants overgrowth inside the cage. And this was observed when green sea urchins *S. droebachiensis* were co-cultured with mussels *Mytilus* spp. to control biofouling at an IMTA site. They were stocked in different numbers in cages. However, their efficiency was only confined inside since they could not access the outside surface of the net [14].

3. Suspension-feeding bivalves as an organic extractive IMTA species

Suspension-feeding bivalves have been successfully used to reduce the organic waste load from the fish culture in the IMTA systems by their assimilation of uneaten fish feed and feces. With this annotation, different species of mussels have been investigated for their integrity as a potential organic extractive IMTA species. However, mussel as an extractive IMTA species is wrapped with inconsistent findings when it comes to effectiveness and efficiency in the IMTA system. The study of Park et al. [9] using *Mytilus galloprovincialis* used as a biofilter for the reduction of inorganic nutrients and particulate organic waste that was potentially issued from the black rockfish culture cage, was found not spatially significant with the control site. Likewise, a report on the absorption efficiency of *Mytilus edulis* and *M. galloprovincialis* conducted in two different locations (Canada and Spain) manifested no differences with their reference sites [15]. The consistent finding was also reported by the same author using *M. galloprovincialis* as co-cultured with red sea bream [16]. This was also supported by another research on *M. edulis* suspended near salmon cages at an IMTA site which showed no significant result with monoculture mussel farms [17]. A recent study on mussel *M. galloprovincialis* also corroborates the same results [18]. However, there are several authors insisted on the viability of mussels as a suspension feeder in the IMTA system based on their findings [19]-[24].

Experiments conducted in the open system such as in pen [16], cage [9] yield no viable findings on mussel as extractive IMTA species. However, researches conducted in the laboratories [19]-[21] showed the importance of mussel species in absorbing organic waste. This scenario was discussed by Sanz-Lazaro and Sanches-Jeres [18] that filter-feeding bivalves seem to be more efficient in confined water such as ponds and enclosed coastal areas such as narrow inlets where currents are weak and, thus, the persistence of particles is high. This was also concurred by Irissari et al., [16] that particulate wastes and potential fish-derived chlorophyll enhancement would be rapidly diluted by the currents, while the placement of bivalves too distant from the fish farm in an environment with high supplies of natural seston may explain the lack of an augmented scope for growth (SFG) of the co-cultured mussels. This was previously proven by the work of Lander et al., [22] that successful utilization of aquaculture-generated organic particles as a food source for marine bivalves cultured in an IMTA system depends both on the occurrence of sufficient particles within the edible size range for the species, and determining the distribution and rate of particle dispersal around the farms. In their findings, particulate organic matter (POM) levels increase 2 to 4 times over ambient levels adjacent to cages but drop to ambient levels after distances of 10 m from the cage. Likewise, daily POM levels were higher at salmon farm cages than reference locations and often correlate strongly with daily fish feeding regimes. In relation to particle range, the majority of particles emits from the aquaculture cages are small (1-10 um), within the utilizable size range for the blue mussel and of very high quality (up to 90% organic content). The authors conclude that pulses of organic enrichment from salmon aquaculture farms are a dependable and bioavailable food source for the blue mussel when grown directly within the particle plume generated from the salmon farm. However, this claim is still debatable, since the dominant source of food is particulate from the cage due to the intensive introduction of feeds that left the mussel no other source of food. And this was confirmed in the recent study, that bivalves particularly the mussel, will feed on fish farming wastes if they are the prevalent food source, but in natural conditions, they would feed preferentially on other available food sources, mainly phytoplankton but also zooplankton. This means that filter-feeding bivalves have a selective diet and seem to prefer plankton over non-living particles in the water column. As recently found out that among all the foods assimilated by mussels, fish farming wastes did not seem to be preferred in any situation, and consequently did not constitute a significant part of their diet [18]. Blue mussels, in particular, have specialized organs called palps that sort and select pre-ingested particles from the seston based on quality (e.g. particle size and a fraction of organic material) and this feeding strategy reflected by smaller isotopic niche widths, particularly when compared to another generalist, suspension-feeding organisms such as ascidians, polychaetes, and other bivalves [24]. On the hand, laboratory findings of Macdonald et al., [20] in estimating feeding response of *M. edulis* was facilitated by grinding into fine particle using a mortar and pestle which was passed through 100 μm mesh and then dissolved in filtered seawater for 24 h with the bulk of particle being <30 μm. In this study, the proximity, immersion time, and particle range size facilitated the absorption efficiency of mussel. The same protocol was also done by Reid et al., [19] in the laboratory where fines diet was produced by grinding the commercial salmon feed and they were aware of pseudofeces production that is why all diets were passed through 100 μm. With this pseudofeces, mussel feces were proven to have very high energetic and nutritional value, where recommendation of culturing deposit-feeders of great commercial value like the sea cucumber, could be cultured alongside the mussel to further exploit the bivalve feces [13], [17]. This might be due to (a) reduction in the residence time of the food through the gut due to higher clearance rate and a limited intestinal capacity; (b) larger percentages of non-absorbed food being lost through the fecal pellets, and (c) increase production of metabolic fecal losses (MFL) that enriched the energetic content of the feces. MFL are endogenous components that are mainly mucus, epithelial cells abraded from the digestive tract, extracellular enzymes, and intestinal bacteria, which are not reabsorbed during digestion and can represent an important energetic loss for bivalves [17].

4. Macroalgae as an inorganic extractive IMTA species

The use of macroalgae in the IMTA system as an extractive species was also tried because of its usefulness as biofilters to remove aquaculture-derived inorganic nutrients, their cultivation may provide significant benefits in terms of water purification for sustainable development of IMTA system. But in the study of Park et al., [9], the expected enrichment in $\delta^{15}N$ (Stable isotope) of macroalgae in the IMTA system was not detected. Undetectable enrichment and spatial shift in $\delta^{15}N$ of macroalgae suggest that the incorporation of caged-fish-derived nutrients by macroalgae is of minor importance. The same observation was also reported using *Caulerpa lentillifera* as a biofilter in the open sea cultivation system held in baskets [25]. This was clearly reviewed by Buschmann et al., [26] that nutrient reduction efficiency and uptake rate of macroalgae depend on both specific properties of the species and culture conditions, including depth, light, water temperature, stocking density, and water turnover rates. In which, in the experiment mentioned above, was affected by either environmental factors.

The use of different species of *Gracilaria* as an inorganic extractive IMTA species have been reported by many authors. Several species of *Gracilaria* were tested and well-known to remove inorganic nutrients from the IMTA system and these are; *Gracilaria lemaneiformis* [27]; *G. chouae* [28]; *G. chilensis* [29]; *G. verrucosa* [30]; *G. vermiculophylla* [31]. Other macroalgae species have also evaluated for their efficiency in the IMTA system and these are; *Eucheuma denticulatum* [25]; *Mastocarpus stellatus* [32]; *Ulva lactuca* [33], [13]; *Saccharina latissima* [34]; *Chondrus crispus* and *Palmaria palmata* [35]; *Laminaria digitata* [36]; *Cladophora parriaudii and C. coelothrix* [37]; *Undari pinnatifida* [31]; *Macrocystis pyrifera* [38]; *Ulva ohnoi* [39]; *Sargassum hemiphyllum* [40].

It was reviewed that macroalgae utilized in the IMTA system, their efficiency to reduce nutrients depends on the species. This was manifested in the work of Largo et al., [25] that seaweeds (*Gracilaria heteroclada* and *Eucheuma denticulatum)* only reduced the levels of nitrate and phosphate in the cage culture of abalone. While, *Gracilaria lemaneiformis* removed dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphate (DIP) as high as 20.98% and 28.61%, respectively compared with the non-IMTA area. This species also reported improving dissolved oxygen (DO) concentration to as high as 7.65 mg/L [27]. This was also corroborated with the previous finding on this species when co-cultured with scallop. *G. lemaneiformis* is known to reduce ammonium and phosphorus of 83.75 and 70.4%, respectively. In this study, the maximum uptake rate of *G. lemaneiformis* was 6.3 and 3.3 $\mu mol\ g^{-1}$ dry weight (DW) h^{-1} [41]. Another report on the species of *Gracilaria* also showed good results is the co-culture of *G. chouae* and *Sparus macrocephalus.* The removal efficiency of NO_3-N, NO_2-N, NH_4-, and PO_4-P as high as 37.76%, 36.99%, 29.27%, and 40.64% respectively, compared with the control site was recorded during the study [28]. The same finding was also documented in *G. chilensis* co-cultured with salmon, with a monthly removal of up to 9.3 g (±1.6) N per meter of the long line [29]. This was also followed by the same result accomplished by *G. verrucosa* that was co-cultivated with the fish *Pseudosciaena crocea*. During the co-culture period, *G. verrucosa* showed efficiency in removing inorganic nitrogen and inorganic phosphate and maintained a more stable dissolved oxygen and chlorophyll a (Chl a) level in the IMTA system. The maximum reduction efficiency of PO_4-P, NO_2-N, NH_4-N, and NO_3-N was 58%, 48%, 61%, and 47%, respectively. The same result was also reported in other marine red algae *Chondrus crispus* and *Palmaria palmata* in terms of nutrient removal capacity. The net nitrogen (N) removal in *Chondrus* was highest at 2.0 kg m^{-2} at both temperatures while *Palmaria* also showed the highest N removal at 2.0 kg m^{-2} at 6^oC but at 4.0 kg m^{-2} at 16^oC [35]. The same finding was also documented in the other groups of macroalgae such as brown algae *Undaria pinnatifida* when tested with *G. vermiculophylla* in the laboratory experiment. High nutrient uptake rates and high nutrient removal efficiency were measured in both species [31]. Another laboratory evaluation of brown algae was done using *Laminaria japonica*, which showed a significant nutrient uptake. It was found that after 36h of incubation, around 42%, 46%, 44% of N and 45%, 42%, 35% of P were removed from three gradients of medium concentrations respectively. The same laboratory findings were also reported when green algae specifically *Ulva ohnoi* was tested. The N fixation rate of the thalli cultivated was 4.2 -13.9 mg N g DW^{-1} day^{-1} [40]. Bioaccumulation efficiency of brown algae was reported using *Sargassum hemiphyllum*. The Carbon (C), Nitrogen (N) and Phosphorus (P) extraction rate of *S. hemiphyllum* cultured in the oyster farm were 15016.90±6341.78, 1112.45±459.81, and 134.69±55.46 mg $thallus^{-1}$, respectively [40].

The capacity of macro-algae to remove nutrients means they have the potential to concomitantly bioremediate polluted waters and generate exploitable biomass. And there are clear differences in growth between species, depending upon the nutrient regime [37]. These growth rates can be perceived in the different co-cultured species of macro-algae as they generate different waste in the IMTA system. This was observed in *G. lemaneiformis* co-cultured with fish *Pseudosciaena crocea* when wet weight 5.3 times greater at the end of the experiment was attained. Concomitantly, the average N and P contents in the tissues of *G. lemaneiformis* were 3.98% and 0.49% dry weight, respectively. And the seaweed was able to remove 2.20% of the N and 0.99% of the P released from the cage [27]. The different growth pattern was also perceived in other species of *Gracilaria* co-cultured with the black sea bream *Sparus macrocephalus.* In this experiment, trash fish was the biggest input of N and P in the cage co-culture area. This resulted in the average contents of N and P of 2.39% and 0.32% dry weight of *G. chouae* with an average specific growth rate of 7.71% [28]. This was clearly manifested in *Mastocarpus stellatus*, a commercially attractive carrageenophyte for foods and pharmaceutics, yield more sulfated kappa/iota-hybrid carrageenan cultivated in the nutrient-rich outflow of a commercial farm. Which led to producing mean biomass of 21 to 40.6 g DW m^{-2} day^{-2} [32]. On the other hand, a seasonal and depth-dependent growth of cultivated kelp *Saccharina latissima* in close proximity to salmon *Samo salar* aquaculture was observed in Norway area. In this study, the rapid growth of *S. latissima* was perceived in spring and early summer which was accompanied by an increase in salmon biomass and feed use in late summer and early summer [34]. The effect of season on red algae was also observed when *G. verrucosa* was co-cultivated with the fish in summer [30]. While some authors suggested an optimal stocking density for the effectiveness of macroalgae in the IMTA system. This proposition was clearly manifested in marine red algae *Chondrus crispus* and *Palmaria palmata* in maximizing productivity and nitrogen removal in a land-based Atlantic halibut farm [35]. This was previously observed by Mao et al., [41] in *G. lemaneiformis* co-cultured with scallop, where nutrient uptake rate and nutrient reduction efficiency of ammonium and phosphorus changed with different cultivation density and time. The same observation about the seasonal effect which was prominently observed in *Macrocystic pyrifera* grown close to salmon farms. In this experiment, light limitation of sporophytes was detected. However, photosynthetic pigments concentrations (chlorophyll a and c, and fucoxanthin) were higher during low-light seasons (winter and early spring) for efficiency but decreased during the summer, due to too much light intensity. And this was associated with a significant increase in nitrogen uptake and nitrate reductase activity [38]. Another factor that should be considered in raising macroalgae in the IMTA system is the balancing ratio of seaweed absorption and fish production. And to know this, DIN and DIP could be a parameter for balancing seaweed absorption and fish production. This was pointed out by Wu et al., [28] in *G. chouae* and *S. macrocephalus* that there should have 231.09 kg of fresh seedlings and the harvested biomass should be 5315.07 kg to balance 836 kg of fry. A 100 ha *G. chilensis* long-line system was suggested by Abreu et al., [29] to reduce effectively (ca. 100%) the N inputs of a 1500 tonnes salmon farm. The same observation was also brought up in the cultivation of *G. chilensis* raised in an intensive tank system that production rates can reach as high as 48.9 kg m^{-2} $year^{-1}$ and is able to remove 50% of the dissolved ammonium in winter, increasing to 80-95% in spring [26]. The DIN balance in the IMTA system was also determined when *G. verrucosa* co-cultivated with fish *P. crocea* was evaluated. Finding suggests the optimal co-cultivation proportion of *P. crocea* to *G. verrucosa* (Fish: Seaweed) in the coastal waters of Xiangshan harbor in the East China Sea, was 1 cage, 144.95 m^2 or 1 kg, 7.27 kg, respectively [30]. The same rationale was also highlighted in removing nitrogen in a land-based Atlantic halibut farm, and it was found out that a 2.0 kg m^{-2} of *C. crispus* was needed while *P. palmata* ranged from 2.0 kg to 4.0 kg m^{-2} depending on the season. In addition, some studies pointed out the balance stocking ration of seaweed and bivalves for the efficient removal of inorganic nutrients. A bivalve/seaweed biomass ration from 1:0.33 to 1:0.80 was recommended for efficient nutrient and for maintaining lower nutrient levels in *G. lemaneiformis* and scallop *Chlamys farreri* [41]. The macro-algae is not only known to extract and absorb inorganic nutrients from the IMTA but also a higher possibility to accumulate metals from the system. This issue was investigated in kelp *Laminaria digitata* cultivated alongside organic Irish salmon aquaculture facilities. It was revealed that cultivation in an IMTA context raised the content of Cu, Mn, and V relative to that in mono-cultivated seaweeds. However, the concentration of metals was within the range of those algae collected from the undisturbed wild population [36]. The heavy metal content such as; Pb, Cd, and Cr was also analyzed in *Sargassum hemiphyllum* but all were below the maximum allowable concentration for aquatic feed. However, higher heavy metal was detected in *S. hemiphyllum* reared with fish rather than with oysters [40].

5. Conclusion

The IMTA system is one of a sustainable and eco-friendly approach among aquaculture activities. This aquaculture practice will not compromise the well-being of the natural ecosystem. Through the synergistic functions of different extractive species where both inorganic and organic waste have been regulated into an optimum level. The recycling of waste within the system is the most vital strategy to alleviate the impact on the neighboring natural habitats. However, the choice and good combination of the extractive species should be considered for an efficient and effective IMTA system.

Compliance with ethical standards

Acknowledgments

The author acknowledges the Graduate Research and Education Assistantship for Technology (GREAT) Program of the DOST-PCAARRD for the scholarship grant. Likewise, Dr. Mae Grace G. Nillos for requiring me to come up with this manuscript.

Disclosure of conflict of interest

The author declares no possible conflict of interest from any individual or institution.

References

[1] Troell M, Joyce A, Chopin T, Neori A, Buschmann AH and Fang JG. (2009). Ecological engineering in aquaculture-potential for integrated multi-trophic aquaculture (IMTA) in marine offshore systems. Aquaculture, 297(1-4), 1-9.

[2] Biswas G, Kumar P, Ghoshal TK, Kailasam M, De D, Bera A, Mandal B, Sukumaran K and Vijayan KK. (2019). Integrated multi-trophic aquaculture (IMTA) outperforms conventional polyculture with respect to environmental remediation, productivity and economic return in brackishwater ponds. Aquaculture, Article in Press.

[3] Ahmed N and Glaser M. (2016). Review can “integrated multi-trophic aquaculture (IMTA)” adapt to climate change in coastal Bangladesh? Ocean and Coastal Management, 132, 120-131.

[4] Nelson EJ, MacDonald BA and Robinson SMC. (2012). The absorption efficiency of the suspension-feeding sea cucumber (*Cucumaria frondosa*) and its potential as an extractive integrated multi-trophic aquaculture (IMTA) species. Aquaculture, 370-371, 19-25.

[5] Biswas G, Kumar P, Kailasam M, Ghoshal TK, Bera A and Vijayan KK. (2019). Application of integrated multi-trophic aquaculture (IMTA) concept in brackishwater ecosystem. The first exploratory trial in the Sundarban, India. In: Jithendran KP, Saraswathy R, Balasubramanian CP, Kumaraguru Vasagam KP, Jayansankar V, Raghavan R, Alavandi SV and Vijayan KK. (2019). World Brackishwater Aquaculture Conference, Journal of Coastal Research, Coconut Creek (Florida), 86, 49-55.

[6] Sun L, Liu H, Gao Y, Jiang Z, Lin F, Chang L and Zhang Y. (2020). Food web structure and ecosystem attributes of integrated multi-trophic aquaculture waters in Sanggou Bay. Aquaculture Reports, 16, 100279.

[7] Hannah L, Pearce CM and Cross SF. (2013). Growth and survival of California sea cucumbers (*Parastichopus californicus*) cultivated with sablefish (*Anoplopoma fimbria*) at an integrated multi-trophic aquaculture site. Aquaculture, 406-407, 34-42.

[8] Israel D, Lupatsch I and Angel DL. (2019). Testing the digestibility of seabream wastes in three candidates for integrated multi-trophic aquaculture: Grey mullet, sea urchin and sea cucumber. Aquaculture, 510, 364-370.

[9] Park HJ, Han E, Lee WC, Kwak JH, Kim HC, Park MS and Kang CK. (2015). Trophic structure in a pilot system for the integrated multi-trophic aquaculture off the east coast of Korean peninsula as determined by stable isotopes. Marine Pollution Bulletin, 95, 207-214.

[10] Yokoyama H. (2013). Growth and food source of the sea cucumber (*Apostichopus japonicus*) cultured below fish cages- potential for integrated multi-trophic aquaculture. Aquaculture, 372-375, 28-38.

[11] Paltzat DL, Pearce CM, Barnes PA and McKinley RS. (2008). Growth and production of California sea cucumbers (*Parastichopus californicus* Stimpson) co-cultured with suspended Pacific oysters (*Crassostrea gigas* Thunberg). Aquaculture, 275, 124-137.

[12] Orr LC, Curtis DL, Cross SF, Gurney-Smith H, Shanks A and Pearce CM. (2014). Ingestion rate, absorption efficiency, oxygen consumption, and fecal production in green sea urchins (*Strongylocentrotus droebachiensis*) fed waste from sablefish (*Anoplopoma fimbria*) culture. Aquaculture, 422–423, 184-192.

[13] Shpigel M, Shauli L, Odintsov V, Ben-Ezra D, Neori A and Guttman L. (2018). The sea urchin (*Paracentrotus lividus*) in an integrated multi-trophic aquaculture (IMTA) system with fish (*Sparus aurata*) and seaweed (*Ulva lactuca*): Nitrogen partitioning and proportional configurations. Aquaculture, 490, 260-269.

[14] Sterling AM, Cross SF and Pearce CM. (2016). Co-culturing green sea urchins (*Strongylocentrotus droebachiensis*) with mussels (*Mytilus* spp.) to control biofouling at an integrated multi-trophic aquaculture site. Aquaculture, 464, 253-261.

[15] Irisarri J, Fernández-Reiriz MJ, Robinson SMC, Cranford PJ and Labarta U. (2013). Absorption efficiency of mussels (*Mytilus edulis*) and *(Mytilus galloprovincialis)* cultured under integrated multi-trophic aquaculture conditions in the Bay of Fundy (Canada) and Ría Ares-Betanzos (Spain). Aquaculture, 388-391, 182-192.

[16] Irisarri J, Fernandez-Reiriz MJ, Cranford PJ and Labarta U. (2014). Effects of seasonal variations in phytoplankton on the bioenergetic responses of mussels (*Mytilus galloprovincialis*) held on a raft in the proximity of red sea bream (*Pagellus bogaraveo*) net-pens. Aquaculture, 428-429, 41-53.

[17] Irisarri J, Fernandez-Reiriz MJ, Labarta U, Cranford PJ and Robinson SMC. (2015). Availability and utilization of waste fish feed by mussels (*Mytilus edulis*) in a commercial integrated multi-trophic aquaculture (IMTA) system: a multi-indicator assessment approach. Ecological Indicators, 48, 673-686.

[18] Sanz-Lazaro C and Sanchez-Jerez P. (2017). Mussels do not directly assimilate fish farm wastes: Shifting the rationale of integrated multi-trophic aquaculture to a broader scale. Journal of Environmental Management, 201, 82-88.

[19] Reid GK, Liutkus M, Bennett A, Robinson SMC, MacDonald B and Page F. (2010). Absorption efficiency of blue mussels (*Mytilus edulis* and *M. trossulus*) feeding on Atlantic salmon (*Salmo salar*) feed and fecal particulates: implications for integrated multi-trophic aquaculture. Aquaculture, 299, 165-169.

[20] MacDonald BA, Robinson SMC and Barrington KA. (2011). Feeding activity of mussels (*Mytilus edulis*) held in the field at an integrated multi-trophic aquaculture (IMTA) site (*Salmo salar*) and exposed to fish food in the laboratory. Aquaculture, 314, 244-251.

[21] Handå A, Ranheim A, Olsen AJ, Altin D, Reitan KI, Olsen Y and Reinertsen H. (2012). Incorporation of salmon fish feed and feces components in mussels (*Mytilus edulis*): Implications for integrated multi-trophic aquaculture in cool-temperate North Atlantic waters. Aquaculture, 370-371, 40-53.

[22] Handa H, Min H, Wan X, Broch OJ, Reitan KI, Reinertsen H and Olsen Y. (2012). Incorporation of fish feed and growth of blue mussels (*Mytilus edulis*) in close proximity to salmon (*Salmo salar*) aquaculture: implications for integrated multi-trophic aquaculture in Norwegian coastal waters. Aquaculture, 356-357, 328-341.

[23] Lander TR, Robinson SMC, MacDonald BA and Martin JD. (2013). Characterization of the suspended organic particles released from salmon farms and their potential as a food supply for the suspension feeder (*Mytilus edulis*) in integrated multi-trophic aquaculture (IMTA) systems. Aquaculture, 406-407, 160-171.

[24] Weldrick CK and Jelinski DE. (2016). Resource subsidies from multi-trophic aquaculture affect isotopic niche width in wild blue mussels (*Mytilus edulis*). Journal of Marine Systems, 157, 118-123.

[25] Largo DB, Diola AG and Marababol MS. (2016). Development of an integrated multi-trophic aquaculture (IMTA) system for tropical marine species in southern Cebu, Central Philippines. Aquaculture Reports, 3, 67-76.

[26] Buschmann AH, Troell M and Kautsky N. (2001). Integrated algal farming: A review. Cahiers de Biologie Marine, 42, 83-90.

[27] Wei Z, You J, Wu H, Yang F, Long L, Liu Q, Huo Y and Hea P. (2017). Bioremediation using *Gracilaria lemaneiformis* to manage the nitrogen and phosphorous balance in an integrated multi-trophic aquaculture system in Yantian Bay, China. Marine Pollution Bulletin, 121, 313-319.

[28] Wu HL, Huo YZ, Han F, Liu YY He and PM. (2015). Bioremediation using *Gracilaria chouae* co-cultured with *Sparus macrocephalus* to manage the nitrogen and phosphorous balance in an IMTA system in Xiangshan Bay, China. Marine Pollution Bulletin, 91, 272-279.

[29] Abreu MH, Varela DA, Henríquez L, Villarroel A, Yarish C and Sousa-Pinto I. (2009). Traditional vs. integrated multi-trophic aquaculture of *Gracilaria chilensis* C.J. Bird, J. McLachlan & E.C. Oliveira: Productivity and physiological performance. Aquaculture, 293, 211-220.

[30] Huo Y, Wu H, Chai Z, Xu S, Han F, Dong Li and He P. (2012). Bioremediation efficiency of *Gracilaria verrucosa* for an integrated multi-trophic aquaculture system with *Pseudosciaena crocea* in Xiangshan harbor, China. Aquaculture, 326-329, 99-105.

[31] Skriptsova AV and Miroshnikova NV. (2011). Laboratory experiment to determine the potential of two macroalgae from the Russian Far-East as biofilters for integrated multi-trophic aquaculture (IMTA). Bioresource Technology, 102, 3149-3154.

[32] Azevedo G, Domingues B, Abreu H, Sousa-Pinto I, Feio G and Hilliou L. (2015). Impact of cultivation of *Mastocarpus stellatus* in IMTA on the seaweeds chemistry and hybrid carrageenan properties. Carbohydrate Polymers, 116, 140-148.

[33] Ben-Ari T, Neori A, Ben-Ezra D, Shauli L, Odintsov V and Shpigel M. (2014). Management of *Ulva lactuca* as a biofilter of mariculture effluents in IMTA system. Aquaculture, 434, 493-498.

[34] Handå A, Forbord S, Wang X, Broc OJ, Dahle SW, Størseth TR, Reitan KI, Olsen Y and Skjermo J. (2013). Seasonal- and depth-dependent growth of cultivated kelp (*Saccharina latissima*) in close proximity to salmon (*Salmo salar*) aquaculture in Norway. Aquaculture, 414-415, 191-201.

[35] Kim JK, Duston J, Corey P and Garbary DJ. (2013). Marine finfish effluent bioremediation: Effects of stocking density and temperature on nitrogen removal capacity of *Chondrus crispus* and *Palmaria palmata* (Rhodophyta). Aquaculture, 414-415, 210-216.

[36] Ratcliff JJ, Wana AHL, Edwards MD, Soler-Vila A, Johnson MP, Abreu MH and Morrison L. (2016). Metal content of kelp (*Laminaria digitata*) co-cultivated with Atlantic salmon in an integrated multi-trophic aquaculture system. Aquaculture, 450, 234-243.

[37] Rossa ME, Davisa K, McColla R, Stanley MS, Day JG and Semião AC. (2018). Nitrogen uptake by the macro-algae (*Cladophora coelothrix* and *Cladophora parriaudii*): Influence on growth, nitrogen preference and biochemical composition. Algal Research, 30, 1-10.

[38] Varela DA, Hernríquez LA, Fernándeza PA, Leal P, Hernández-Gonzáleza MC, Figueroac FL and Buschmanna AH. (2018). Photosynthesis and nitrogen uptake of the giant kelp (*Macrocystis pyrifera,* Ochrophyta) grown close to salmon farms. Marine Environmental Research, 135, 93-102.

[39] Yokoyama H and Ishihi Y. (2010). Bioindicator and biofilter function of *Ulva spp.* (Chlorophyta) for dissolved inorganic nitrogen discharged from a coastal fish farm-potential role in integrated multi-trophic aquaculture. Aquaculture, 310, 74-83.

[40] Yu Z, Robinson SMC, Xia J, Sun H and Hu C. (2016). Growth, bioaccumulation and fodder potentials of the seaweed (*Sargassum hemiphyllum*) grown in oyster and fish farms of South China. Aquaculture, 464, 459-468.

[41] Mao Y, Yang H, Zhou Y, Ye N and Fang J. (2009). Potential of the seaweed (*Gracilaria lemaneiformis*) for integrated multi-trophic aquaculture with scallop (*Chlamys farreri*) in North China. Journal of Applied Phycology, 21(6), 649-656.

How to cite this article

Jumah YU. (2020). A review on waste absorption efficiency of different extractive integrated multi-trophic aquaculture (IMTA) species: Implications in coastal and offshore aquaculture waste management. GSC Biological and Pharmaceutical Sciences, 11(2), 257-264.